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Chapter 2

A Lathe and the Material *Sphaera*: Astronomical Technique at the Origins of the Cosmographical Handbook



Richard J. Oosterhoff

Abstract Even though cosmographers loved to drape their discipline in the ancient dignity of Ptolemy, actual manuals of cosmography often depended on Johannes de Sacrobosco's medieval introduction to spherical astronomy. In fact, certain strains of cosmography shared organization, principles, and even visual apparatus with Sacrobosco's *Sphaera* and its growing commentary tradition, to the extent that these cosmographies can be seen as themselves commenting on the *Sphaera*. This paper traces the origins of certain Renaissance cosmographical handbooks to the commentary on the *Sphaera* by Lefèvre d'Étaples and his colleagues at Paris around 1495. By focusing on the visual elements of this commentary, its instructions for calculating techniques, and the emergence of the “lathe” model of the “material sphere,” this chapter argues that one of the mixed mathematical genres now seen as most characteristic of the Renaissance—cosmography—in fact was based on a medieval textbook.

1 Introduction¹

The first printed commentary on the *Sphaera* of Johannes de Sacrobosco (died ca. 1256) was published at Paris in February of 1495. Early in the book the Paris arts master Jacques Lefèvre d'Étaples (ca. 1455–1536) turns to the artisan's workshop to explain the sphere. There one would find a “description of wonderful efficacy,”

¹I wish to thank Matteo Valleriani for helpful comments, the other contributors to this volume for stimulating conversation, and an anonymous reviewer for a useful suggestion. This research has been supported in part by the European Research Council under the European Union's Seventh Framework Programme (FP7/2007–2013)/ERC grant agreement no 617391.

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which clearly teaches (insofar as sensible matter can take it) how to make an artificial sphere. Artisans in our time who wish to fashion figures with a lathe in metal or another material should find its use worth its weight in gold. So, having taken a compass of thin steel or iron, a semicircle is inscribed on some line which is then cut out from the arc to the diameter, and moreover the diameter in between as well; then it is fit for cutting and dividing, and you have a tool very much suited for turning a sphere, just as a compass is for turning circles.²

The example of turning a sphere on a lathe makes a point about the status of astronomy, a classic example of a mixed science. The compass, a paradigmatic instrument of geometry, embeds the description firmly within the objects of mathematical study: lines and curves. At the same time, Lefèvre sets before his readers a concrete example, a lathe with a semi-circular blade (Fig. 2.1). A compass inscribes the edge of a tool, cutting the curve into the surface of a metallic chunk.

As we shall see, the lathe is a visual analogy that pervades later versions of the *Sphaera*; but this tradition originates in Lefèvre's commentary. As the first printed commentary within the genre, the *Textus de sphaera* shows the changes the printed medium and new modes of commentary could bring to the *Sphaera*.³ Lefèvre's version was widely available in the first part of the sixteenth century, through the two great exporting centers of print, Paris and Venice. In 1499 it was republished in Venice, together with commentaries by Cecco d'Ascoli (ca. 1269–1327) and Capuano de Manfredonia (died ca. 1490)⁴; Lefèvre's *Textus de sphaera* thereafter formed the core of omnibus editions (1508, 1518, 1519, 1531), which included cosmographical writing such as travel narratives of Amerigo Vespucci (1454–1512) and medieval alternatives to Sacrobosco such as the textbook of spherical astronomy by Robert Grosseteste (ca. 1175–1253) (Barker 2011). On its own, the *Textus de sphaera* remained a venerable standard in the printing repertoire of Henri Estienne the Elder (1460–1520) (printed in 1500, 1503, 1507, 1511, 1516) and his successor Simon de Colines (ca. 1480–1546) (1521, 1527, 1532, 1534, 1538).⁵ Colines framed the work with new frontispieces and marginal notes by the next generation's most eminent mathematical practitioner, Oronce Fine (1494–1555),⁶ but retained the diagram woodblocks and layout of the commentary's original edition of 1495.

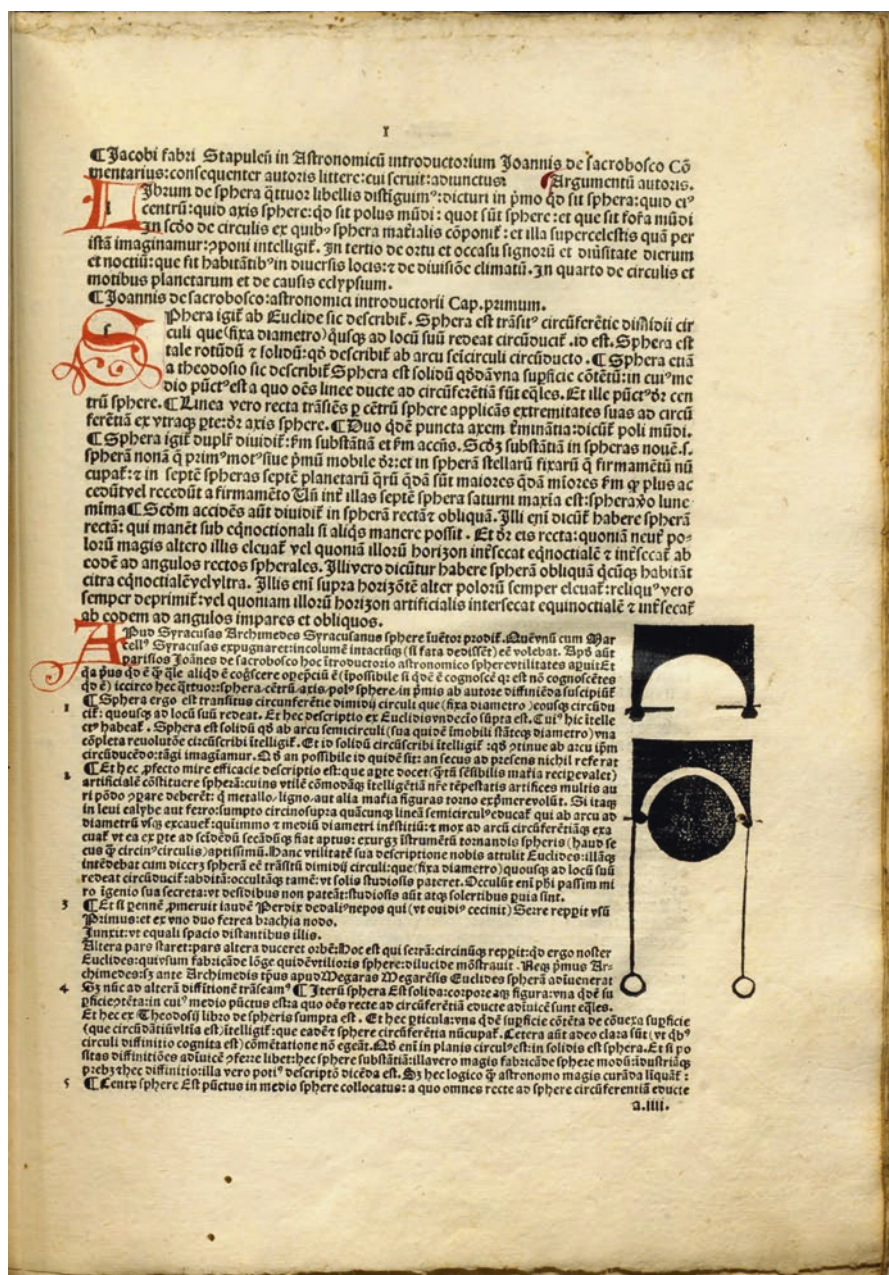
²(Lefèvre 1495, a iiiir): “Et hec profecto mire efficacie descriptio est, que aperte docet (quantum sensibilis materia recipere valet) artificialem constituere spheram, cuius utilem commodamque intelligentiam nostre tempestatis artifices multi auri pondo comparare deberent, qui metallo, ligno, aut alia materia figuras torno exprimere volunt. Si itaque in levi calybe aut ferro, sumpto circino supra quancunque lineam semicirculus educatur qui ab arcu ad diametrum usque excavetur, quin immo et medium diametri interstitium, et mox ad arcum circumferentiamque excavatur ut ea. ex parte ad scindendum secundumque fiat aptus, exurget instrumentum tornandis spheris (haud secus quam circinus circulis) aptissimum.”

³The scholarly framework here includes (Johnson 1953; Gingerich 1988, 1999; Hamel 2004, 2006, 2014; Pantin 2001, 2012; Crowther and Barker 2013; Oosterhoff 2015; Valleriani 2017).

⁴On Francesco Capuano de Manfredonia's work concerning Sacrobosco's *Sphaera* see (Chap. 4).

⁵The relationship of Lefèvre to these printers is addressed by (Armstrong 1952; Veyrin-Forrer 1995). (Rice 1972) edited Lefèvre's prefatory letters to these works. For further context, see also (Bedouelle 1976).

⁶On Oronce Fine's work concerning Sacrobosco's *Sphaera* see (Chap. 8).



The case of the lathe evokes a central problem of early modern mathematical learning: how does one learn to manipulate mathematical tools with integrity, while mapping them onto the physical world? To meet this challenge, I shall show that Lefèvre made use of a resource new in the fifteenth century, Ptolemy's rediscovered *Geographia*.⁷ The result was that the first printed commentary on Sacrobosco's *Sphaera* inaugurated a particular tradition of cosmographical handbooks. I will suggest that the merger of astronomy with new handbooks for making maps had two implications for the ramifying genres of the *Sphaera*. The first is a higher emphasis on competent *practice* within astronomy, raising the epistemic value of technique even among beginners. Second, later versions of Sacrobosco's *Sphaera* refocused attention on the metaphorical nature of astronomical reasoning—the transfer from model to reality—a shift embodied in Lefèvre's material metaphor of the lathe.

2 Mathematical Reform

Lefèvre's *Textus de sphaera* of 1495 was the first public result of a turn to mathematics at Paris.⁸ The goal was to renovate the University of Paris, Lefèvre explained in his prefatory letter to a bureaucrat in the Paris Parliament. After all, he reported, Plato had said that mathematics “is of the greatest importance not only for the republic of letters, but also for the civil republic—Plato thinks those with the best natures especially should be taught in it.”⁹ Lefèvre named George of Trebizond (1395–1486)—an arch-Aristotelian in Florence and Rome who had written a lengthy controversial commentary on Ptolemy's *Almagest*—as an example of how mathematics might benefit learning (Monfasani 1976, 105–8; Shank 2002, 2007a). Lefèvre himself was already deep into his project, having prepared an extensive revision of the *Elementa arithmetica* of Jordanus (fl. thirteenth century). The following year, he would have this edition printed together with his own introductory study of arithmetic, an innovative study of Pythagorean music theory, and the arithmetical game *Rithmimachia* (Lefèvre 1496).

Lefèvre carried out this project during a 17-year tenure as regent master of the Collège du Cardinal Lemoine, one of the older and smaller colleges of the University of Paris, with the help of an expanding circle of students. His right hand man was Josse Clichtove (1472–1543), who eventually became a leading theologian in the powerful Paris faculty of theology, but apprenticed in print as Lefèvre's corrector and editor in his *Paraphrases on Natural Philosophy* of 1492 (Lefèvre 1492; Massaut 1968). In the summer of 1495, after the *Textus de sphaera* was already published, Lefèvre met Charles de Bovelles (ca. 1475–ca. 1566), who immediately

⁷For the subject of the rediscovery of Ptolemy's *Geographia*, I build on an argument sketched in (Oosterhoff 2018, 133–50).

⁸On this mathematical turn more generally, see (Oosterhoff 2018) and (Chap. 3).

⁹(Lefèvre 1495, a iv; Rice 1972, 27): “Mathemata, inquit, que (si Platoni septimo de republica credimus) non modo reipublice litterarie, sed et civili momentum habent maximum, et in his (ut sentit Plato) precipue erudiendi sunt qui naturis sunt optimis.”

joined him at Cardinal Lemoine. Bovelles later identified this moment as the origin point of his life-long preoccupation with mathematical figures and numbers in philosophy, responding to Ramon Lull (1232–1316) and Nicholas of Cusa (1401–1464).¹⁰ The extent to which Lefèvre depended on such close students in making his books, especially his mathematical books, can be seen in the *Textus de sphaera*, where in the prefatory note Lefèvre recorded a debt to his *familiaris* Jean Grietan for doing many calculations; the colophon also thanked three correctors besides Grietan. Lefèvre often worked with students: Clichtove and Bovelles published a suite of textbooks on number theory, practical arithmetic, geometry, optics in 1503, which took its starting point in an extended commentary on Lefèvre’s epitome of arithmetic, and closed with Lefèvre’s *Astronomicon*, a contribution to the genre of theorics that was usually read after the *Sphaera*.¹¹ This mathematical project was marked by intensive habits of collaboration (Oosterhoff 2019b).

These habits matched a language of friendship and harmony. The preface to the *Textus de sphaera* closed on the *benevolentia* or goodwill Lefèvre shared with his patron. The idiom of shared goodwill as a bond between two people built on Aristotle’s (384–322 BCE) account of friendship.¹² It also echoed the intuition that the world’s deep, hidden structures include patterns of sympathy and repulsion, friendship and repulsion. Lefèvre hinted as much in his manuscript treatise *De magia naturali* of the mid-1490s—just when he published the *Textus de sphaera*—which offered a learned astrology organised around these forces and included a book on “Pythagorean magic.”¹³ Lefèvre’s interest in arithmetic and its subaltern science of music revolved around the Pythagorean notion of concord. Mathematically, the idea addresses the relation of quantities, ratios, or proportions: number theory or arithmetic offers a classification scheme for understanding different ratios, while music theory offers a way to use ratios of small numbers to divide the scale. This could have much larger implications. Lefèvre’s edition of Euclid’s (fifth century to fourth century BCE) *Elements* set a new humanist translation alongside the classic medieval translation of Campanus of Novara (1220–1296), who introduced Book 6 with a long excursus on proportion as the *habitus* or relation of any one thing to another, citing Aristotle’s *Categories* as support (Lefèvre 1517, 57r). Although the immediate question was how to relate arithmetical numbers to geometrical points and lines, the discussion opened larger questions. Campanus cited Boethius (early sixth century) on music, noting that the question related to sound. He also cited Plato’s (ca. 428–ca. 348 BCE) *Timaeus*, which suggested that weights and powers relate in mathematical proportion. The fact that arithmetic theory seemed to get at

¹⁰ (Bovelles 1511, 168v): “Parhisiis, quod anno 1495 peste affecti sunt...te ruri illustrem disciplinarum solem ostenderi. Tu nempe per introductiones numerorum, per arithmetice discipline preludia, Pythagorico more, totius mei philosophici profectus ac litterarii studii extitisti causa.” On Bovelles more generally, see (Cassirer 1927; Faye 1998; Klinger-Dollé 2016).

¹¹ The *Astronomicon* was republished under the editorship of Oronce Fine in 1515, and again in a deluxe edition with Clichtove’s commentary in 1517.

¹² This culture of friendship and its relation to mathematics is described in (Oosterhoff 2016).

¹³ Book 2 is titled “de Pythagorica philosophia que ad Magiam introductit” (Olomouc, University Library, MS M.I.119, 198r). See (Mandosio 2013 and 2018).

the forces governing the physical experience of sound, weight, and natural powers offered a suggestive hint that mathematics could explain and even control physical causes too.

These intuitions sparkle under the surface of Lefèvre's commentary on the *Sphaera*. At the beginning of Book 2, he added to his explanation of the great circles (equator, zodiac, colures, etc.) a report from the *magi*. Magicians, he said, divide the heavens into four points: the eastern one is that of God; the midday point is that of "the intelligences;" the western point belongs to the fallen dead (*caducorum*), while the midnight point to "evil powers" (Lefèvre 1538, 9r–v). Elsewhere, on the topic of "crepuscular risings" he alerted readers that those who concern themselves with such matters are not the good sort of *mathematicus*, engaged as they ought to be with arithmetical, musical, geometrical, or astronomical profit. Rather, the *mathematici* who indulge in such topics are "those we call vain and poisonous, such as we read poisonous wise-women were, especially that notorious Thessalian, or Circe, or Medea..."¹⁴

Despite evident familiarity with operative magic, Lefèvre quickly steered readers clear of such dangerous waters. The account of the four points of heaven turns into an anodyne analogy for contemplative theology; the movement of the heavens from first light, to midday sun, shadow, and then darkness "unfolds the movement of contemplation" (*contemplationis motus explicatur*). Lefèvre urged readers to read this in light of Romans 1:20, which proclaimed that "through those visible things that were made, we sense an understanding of the invisible things of God."¹⁵ Although he recognised that "the magicians foretell great and hidden things through these four points," Lefèvre offered a deflationist reading: readers should learn to use such insights into the movements of the heavens in order to gain an understanding (*idea cognita*) of everything, to feed a cycle of higher intellectual insight, not to manipulate the occult forces of the natural world.

In hindsight, we can distinguish both Platonist and Aristotelian sources on mathematics flowing into Lefèvre's approach to the *Sphaera*. The broadly Platonist assumption that ideas are the most powerful objects that exist also nourished the Pythagorean preoccupation with numbers as the most fundamental category of being, stretching even to the possibility that numbers might underly magic. These ideas were filtered through a Christian modulation of Plato, especially through late antique authorities such as Pseudo-Dionysius (early sixth century) and Boethius, both reimagined by the fifteenth-century cardinal Nicholas of Cusa (1401–1464)—whose *Opera omnia* Lefèvre and colleagues edited in 1514. Using such resources, Lefèvre offered a middle way between realism and nominalism: number exists out there in the world, but is only accessed mentally through human creative conjectures. In fact, the human mind *makes up* number and so, in the act of measuring, imitates God's creation of number in the world. Since Lefèvre thought that late

¹⁴ (Lefèvre 1538, 16r): "Eo enim tempore quod a crepusculo vespertino principium sumit, mathematici utuntur, non qui Arithmeticen, Musicen, Geometricam, Astronomicamque dignitatem profitentur, sed quos vanos veneficosque nuncupamus, qualibus veneficis sagisque mulieribus, maxime infamis Thessalia fuisse legitur, qualem fuisse Circen, qualemque Medeam..."

¹⁵ (Lefèvre 1538, 9v): "ex iis quae visibilia facta sunt, invisibilia dei comprehensa cernamus."

antique Platonists had actually stolen the insights of New Testament thinkers, he believed this roughly Platonist framework to be distinctively Christian. But like the ancient Platonists themselves, within this general framework, he had no trouble using Aristotle as a reliable guide in specific domains of scholarly study such as natural philosophy, meteorology, or astronomy.¹⁶

By making mathematics foundational for inculcating Aristotelian intellectual virtue, Lefèvre emphasised an educational program of soul-craft slightly different from Platonist mentors such as Marsilio Ficino (1433–1499) (Chap. 5). This can be seen clearly in Lefèvre’s account of the “fatal number” that Plato gave in the *Republic* as the enigmatic number that encoded the shifts between political regimes. Aristotle had commented on the passage in his *Politics*, in a passage that elicited Lefèvre’s longest scholium in his entire study of the work. Ficino had offered a magical explanation of the passage: souls were constructed as a geometrical set of relations, so to change political systems or groups of souls was at root a matter of manipulating mathematics.¹⁷ For Ficino, contemplation was valuable because it had pragmatic uses. Lefèvre reversed this approach. He agreed with Ficino that the number was 1728, and the bulk of his comments coached the reader through the mathematical theory and techniques necessary to arrive at this conclusion. But he constantly warned his reader to treat this solely as a matter of mathematical exegesis, not vatic soothsaying.¹⁸ The point of moving one’s mind along the paths of a mathematical problem *was just the exercise of the soul*, not for technological power, but for the pedagogical acquisition of *habitus*. Although the goal was theoretical, motivated by a contemplative vision of exercising the soul’s virtues, this metaphysical end was only achieved through an operative emphasis on practical technique.

3 Vision and Technique

What techniques then did a reader exercise in the *Sphaera*? Since nearly every university student in Renaissance Europe encountered Sacrobosco’s *Sphaera* at some point in their studies, its opening pages give an especially good snapshot of what standard mathematical knowledge could look like. After all, astronomy was a classic example of a “mixed” science, taking the pure principles of geometry and applying them to the moving heavens.¹⁹ Therefore a student opening the *Sphaera* needed

¹⁶On Lefèvre’s theory of numbers, see (Oosterhoff 2018, 199–204); on his self-positioning vis-à-vis Plato and Aristotle, see (Oosterhoff 2019a).

¹⁷The relevant passages are Plato, *Republic*, 8.546a1–d3; Aristotle, *Politics*, 5.1316a1b26. See (Ficino 1491, 225r; 1496, unnumbered final quire). On Ficino’s metaphysics here, see (Allen 1994, 1999).

¹⁸(Lefèvre 1506, 87r): “verum vaticinari ex illis querere, et futili coniectura divinum scrutari velle secretum, vanum.”

¹⁹Most students could have traced this classic account to the quadrivium of Boethius: e.g. *De arithmetica* I.1.

to recall the language of geometry (the exotic vocabulary of points, lines, surfaces, and solids) in order to reimagine the heavens as an orderly *machina mundi*, which was what Sacrobosco named the cosmos early in Book 1. With these tools in hand, the risings of stars, the conjunctions of planets, and the shadows of eclipses might be measured, explained, and—with the help of Lefèvre’s commentary—calculated.

Before 1495, a student gained mostly qualitative and general geometrical knowledge from the *Sphaera*. As other chapters in this book reveal, the genre expanded and diversified in many ways between the first printed editions of 1472 and the late sixteenth century. The first editions were slim octavos, visually sparse, with no prefatory material, and although they left space for diagrams, it appears that readers were expected to pen them in (de Sacrobosco 1472a, b).²⁰ Erhard Ratdolt (ca. 1447–ca. 1527) introduced only three woodcuts in 1478 and 1482; these grew to 24 in his edition of 1485.²¹ Many of these appear to be available in the manuscript tradition. The next major change occurred in a Venetian edition of 1488, which added a lengthy prefatory note as well as a “definition of the sphere and of certain presupposed geometrical principles.”²² These five pages gave the terminology of circumferences, poles, lines, curves, and surfaces, etc., accompanying a regime of diagrams; this can be seen as the first step towards including commentaries with the printed *Sphaera*.

This expansion of the *Sphaera*’s visual apparatus between 1485 and 1495 suggests an important function for Sacrobosco in this period. Certainly, the competition of printers partly explains the proliferation of diagrams. But those printers seem to have spotted a need in late medieval learning of astronomical phenomena. Students needed to develop their capacity to image mentally—to imagine—the mathematical structure of heavenly movements. Imagination could be unreliable, of course, and since Pierre Duhem a classic strand in the history of science has focused on this language of *imaginatio* as a problem in “saving the phenomena.”²³ Recent scholarship has noticed that this language was ambivalent—the faculty of imagination also mediated trustworthy knowledge (Crowther and Barker 2013) (Chap. 9).²⁴ For example, mental imaging allowed one to identify the mathematical shape of physical bodies. A culminating proposition in Sacrobosco observes how “Euclid imagined that a sphere is caused by the revolution of a semicircle firmly set on a chord, returned around to the place it started from.”²⁵ The geometrical rudiments added to fifteenth-century manuscript and printed editions of the *Sphaera* suggest the effort

²⁰ For a more detailed overview of the developments described in this paragraph, see (Baldasso 2007), and especially (Crowther and Barker 2013).

²¹ This edition, and many others from Venice and Paris up to 1500 also included the *Theorica* of Georg Peurbach and the *Contra Cremonensem* of Johannes Regiomontanus.

²² (de Sacrobosco 1488, a4r): “Diffinitio sphaerae et de quibusdam principiis geometricis supponendis.”

²³ For an overview of this historiography, see (Shank 2002; Barker 2011).

²⁴ A wideranging study of vision’s ambiguous place in early modern culture is (Clark 2007).

²⁵ (de Sacrobosco 1490, a6r): “Imaginatus est Euclides quod sphaera causetur ex revolutione semicirculi super chordam suam firmiter permanentis donec revertitur ad locum a quo caepit circumduci.”

to foster a certain kind of spatial imagination as part of the everyday cultural and mental furniture of Renaissance intellectual life.

The same observation might be made of many diagrams throughout these early printed editions: the concentric orbs of the planets; the images of small stick figures walking around the globe as they observe the stars rising over the horizon (an argument for the sphericity of the world and heavens); the ubiquitous ship with observers at its mast and on its deck, in which the lower sailor's line of sight is blocked by the earth's bulge; the smiling sun as the moon eclipses it for a viewer from earth.²⁶ These figures supply the toolkit needed to reframe the heavenly bodies as mathematical objects within the mind. This diagrammatic tradition performs an important function—but it is sharply limited. It does help the mind gain certain geometrical intuitions and abstractly apply them to a heavenly model. But these diagrams do little to help one calculate anything. Before 1495, Sacrobosco did little to teach students the specialist skills of quantification.

This is by no means a presentist observation. Contemporaries would have recognised this point. The main purpose of early modern astronomy, Robert Westman has shown in abundant detail, was prognostication (Westman 2011). Even those interested primarily in the theoretical description of heavenly models—as Lefèvre claimed to be—were acutely aware of their utility for medicine or courtly advice. Physicians and courtly astrologers therefore depended on techniques of calculation to cast a horoscope: they had to understand the locations of the heavens in the past, and to decipher where they would be in the future. A would-be prognosticator required several things beyond some geometrical intuitions about how the heavens move.²⁷ First, a set of tables locating heavenly bodies, usually based on the thirteenth-century tables associated with King Alphonse of Spain, or (increasingly) the newly calculated tables of Johannes Regiomontanus (1436–1476). Second, a set of canons, which supplied the protocols for calculating from those tables. Third, skill in sexagesimal arithmetic, since all calculations were in degrees, minutes, and seconds. Fourth, and optionally, a prognosticator might take a shortcut with a calculation device, such as an equatorium or an astrolabe—these allowed one to read values off the instrument, rather than perform laborious calculations. None of these elements were part of Sacrobosco's introduction to the sphere.

All of these, however, were integrated into Lefèvre's commentary on the *Sphaera*, to one degree or another. The edition of 1500 even added Bonet de Lattes's (fifteenth century to sixteenth century) short treatise on a miniature astrolabe, which Lefèvre had found in his travels to Italy.²⁸ In the shape of a ring intended to fit a finger, it was too small for meaningful observations or for precise calculations—but it gestured towards the company Lefèvre expected his treatise to keep.

²⁶ (Crowther and Barker 2013, 442–63) have categorized these into three kinds of images: abstract geometrical diagrams; hybrid images that are diagrammatic with naturalistic features (such as the ship); and cosmic section, i.e. the cross-sections of the planetary orbs.

²⁷ An overview of recent work in this area can be found in (Chabás and Goldstein 2014; Kremer and Husson 2012).

²⁸ The first edition is (de Lattes 1493).

Throughout the commentary itself, Lefèvre took his reader by the hand, explaining the techniques needed to perform calculations. This starts with the opening *Introductoria additio*, which offers a brief overview of the same definitions of points, lines, and circles that we have already seen in versions of Sacrobosco from the previous decade. Lefèvre concluded this note with a telling primer on sexagesimal arithmetic. Although it is clear from annotated copies that readers did in fact sharpen their skills on the two specimen calculations he included, nevertheless Lefèvre sent readers to other sources if they wished to become proficient: “these things are added about the physical mode of calculation, not because this is enough for abacus or astronomical calculation, but so that those educated in this astronomical instruction might consult calculations and experts in calculation.”²⁹

Beyond his introduction to sexagesimal arithmetic, Lefèvre offered a series of tables for astronomy and cosmography. Elsewhere I have discussed in some detail the series of astronomical tables, but a few words about their function will be significant here (Oosterhoff 2020). In Book 3, Sacrobosco sets the topic of “risings,” namely the times when the stars in the various signs of the zodiac rise over the eastern horizon. This is a fundamental task for spherical astronomy: it allows one to determine the speed of the heavenly sphere’s movement. Therefore not only are these tables the basis for calculating the location of any other star at a given time, but they also set the starry backdrop against which to calculate the movement of the lower planets. The task is fairly straightforward when an observer stands at the equator (“right sphere”), so that is where Lefèvre begins. His commentary constructs six rules based on Sacrobosco’s text, and joins them to worked up specimen examples. Using short, simplified tables, he connects the movement of the heavens with the passing of time: a quarter of the zodiac has passed when a quarter of a day has passed, and so on. The matter is simplified since, even though the zodiac wobbles with the sun’s annual movement through the ecliptic, this wobble is symmetrical at the equator. The basics set, Lefèvre complicates the picture, moving the observer north from the equator, to the latitude of Paris. From this perspective (“oblique sphere”), the zodiac speeds up and slows down irregularly from the observer’s perspective. Here Lefèvre’s rules help the reader to respond and recalculate from a realistic point.

By this point in the text, the reader has worked through enough techniques to read a table of risings or ascensions. Lefèvre includes, therefore, two full tables of ascensions that synthesize the information taught in the earlier rules: one for the equator and one for the latitude of Paris. These are not intended to replace the much fuller tables used by professionals. In fact, Lefèvre offered recommendations to readers who wished to work with actual tables. They should avoid the older Alphonsine tables, “for they are not precise. Instead, it is from the tables of ascensions of Johannes Regiomontanus...that they should compute.”³⁰ Lefèvre

²⁹(Lefèvre 1538, 3r): “Haec de abaci physica ratione adiecta sunt, non quia ad abacum astronomicumque calculum sufficienter introducunt, sed ut calculum calculique peritos consulant, qui hoc astronomico instituto sunt informandi.”

³⁰(Lefèvre 1538, 20r): “Caveant tamen abacistae...per ascensiones tabulis Alphonsinis adiectas numerando perquirere, nam praecisae non sunt; sed potius per tabulas ascensionum Ioannis Nurembergi ubilibet...computent.”

did not claim that his commentary on Sacrobosco was everything needed for the competent astrologer. Nevertheless, the student who had mastered it could approach the canons and tables of professionals with some degree of confidence, now able to visualise the movements of the heavens and also to relate those movements to tables of measurements.

4 Introducing Cosmographical Practice

The other set of tables in Lefèvre's commentary on the *Sphaera* addressed cosmography. The word "cosmography" was a moving target throughout the period. The discipline itself was new to the Renaissance. Medieval authors had provided narrative accounts of cities, rivers, and lands, but the word gained new associations after ca. 1410, when one of Manuel Chrysoloras's (1353–1415) students Jacopo d'Angelo (ca. 1360–1411) finished the translation of a text his master had brought from Greece, Ptolemy's *Geographia*.³¹ By titling his Latin version *Cosmographia*, d'Angelo linked the term to Ptolemy's practice of mapping: projecting the grid of stars on the celestial sphere onto the terrestrial globe—then projecting this globe, in turn, onto the flat surface of a map. Using this insight, the bulk of the book comprised lists of longitudes and latitudes for around 8000 cities, along with three modes of projection that would allow users to construct maps from these coordinates. By 1533, when Erasmus of Rotterdam (1466–1536) wrote a preface for the Basel *editio princeps* of the Greek text, the book had been published in dozens of editions and had spawned a whole subgenre of introductory handbooks.³²

We have often identified the earliest cosmographical handbooks as those by Matthias Ringmann (1482–1511) (1507) and Heinrich Glarean (1488–1563) (1513).³³ Some have loosely linked these handbooks to Sacrobosco. Benjamin Weiss suggested that the reading patterns of Sacrobosco's *Sphaera*—heavily annotated witnesses to underlying manuscript notes and circles of readers—are analogous to the ways readers of Ptolemy's work labored over practices of recalculating and remapping the longitudes and latitudes in his *Cosmographia*. Such specialist readers existed, as we know from their noisy complaints that Ptolemy's data was incorrect, and by the 1530s Ptolemaic techniques of mapmaking were common across Europe. I would claim this connection between the reading practices of Ptolemy and Sacrobosco is more than an analogy; in fact, beginning in 1495 with Lefèvre's publication of the *Textus de sphaera*, commentaries on the *Sphaera* actually introduced students to the techniques of Ptolemaic cartography.

³¹ A range of useful recent studies includes (Tessicini 2011; Mosley 2009; Dalché 2009; Hankins 2003).

³² On expansion of Ptolemaic handbooks and cartography, see (Buisseret 2003, 49–70; Weiss 2011). Erasmus's involvement in the edition of Ptolemy was minimal, as convincingly argued by (Reedijk 1989).

³³ Glarean's work is in manuscript (Glarean 1513) and was first printed in 1527.

We can see this in Lefèvre's commentary on Book 2 of the *Sphaera*, which introduces the major and minor circles of spherical geometry. Major circles are fundamental reference points for cartography, as they divide the sphere's surface into equal halves or hemispheres: e.g. the equator, the meridian, and the horizon. The equator runs east-west, while a meridian evenly splits the earth by running north-south. When projected up onto the heavenly sphere of the stars, these circles define the celestial equator, meridians, and celestial horizons—the latter is the major circle that defines the hemisphere of stars visible to any observer on earth. Minor circles are smaller circles on the surface of the globe, which divide the sphere unequally: e.g. the colures such as the lines of Cancer and Capricorn that lie above and below the equator; the smallest of these minor circles are the arctic and antarctic circles. Taken together, these various circles slice the sphere into five zones.

Lefèvre's commentary draws out the key assumption necessary for Ptolemaic cartography, namely that "the sphere" is *both the earth and the heavenly system of concentric orbs*. The zodiac is therefore the belt of stars embedded on the inner surface of the outer starry sphere, a belt that follows the celestial equator; but the zodiac also includes the space below it, projected ever more narrowly onto the earthly sphere. "And in this sense we may properly say that the planets are *in signs*" (Thorndike 1949, 125). To illustrate this point, previous versions of the *Sphaera* included an image of what Sacrobosco called a "pyramid" based on the zodiac, with its apex at the center of the earth (Fig. 2.2 left). Lefèvre's version of the pyramid is clearer; but his biggest change is to present a sphere in which the major circles of longitude are assembled, hinting at the gores of a globe (Fig. 2.2 right). Around the sphere's middle is the belt of the zodiac giving a physical sense of the pyramid bases linked together as a cross section of the celestial globe. To clarify the arrangement, a third diagram presents this cross section from above, like an orange sliced in half,

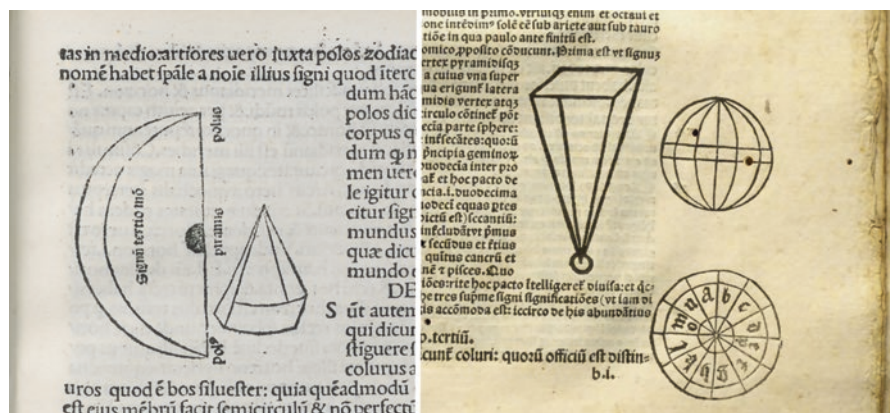


Fig. 2.2 Two illustrations of the spherical portion shared by earth and heaven, where the zodiac is the base of a pyramid with an apex at earth's center. Left: From (de Sacrobosco 1490 (Venice), b ii r). Bavarian State Library, Ink I-507, <http://mdz-nbn-resolving.de/urn:nbn:de:bvb:12-bsb00020990-0>. (<http://hdl.handle.net/21.11103/sphaera.100885>) Right: From (Lefèvre 1516, b i r). University Library Basel, CC II 7:3, <https://doi.org/10.3931/e-rara-49305/> Public Domain Mark

revealing the pyramids fanning out from the center of the earth where their points meet. The image crystallises the assumption that the geometry of the heavenly spheres maps directly onto earth.

From this point, Lefèvre offers tools for deploying spherical astronomy to map locations on earth. In passing, Sacrobosco mentions that the meridian line is known as the longitude of a city. Lefèvre specifies precisely how to calculate the difference in degrees and minutes of two cities, and how to convert a difference of coordinates into a difference of time (useful for calculating horoscopes). A specimen example compared the time in Paris and Jerusalem, where the sun rises 2 hours and 47 minutes earlier. This gave the reader a simple task in order to begin using the central exhibit of the text: a four-page table of longitudes and latitudes, “taken from Ptolemy.”³⁴

Longitude—physically measured by travellers and shared in such tables—would have posed students no great challenge, since there was little to be done but read it off the table.³⁵ The more interesting technical challenge was to measure latitude, based on the altitude of the sun. Of course, this required additional information. The sun’s altitude changes over the course of the year, between its maximum height at the summer solstice, and maximum depth in winter. As Sacrobosco pointed out, these solstitial points determine the place of the minor circles at the tropics of Cancer and Capricorn (since the sun would be in those signs during June and December). But if one can account for the sun’s elevation, the geometry of greater and minor circles will allow a novice astronomer to calculate the latitude of a given location. More generally, the same techniques allow one to set a given location in relation to the various circles drawn on a map. Lefèvre presented these techniques as a set of seven rules, adding a small table of worked examples for the reader’s benefit (Fig. 2.3).

Is this astronomy or cosmography? Lefèvre’s specimen examples emphasised that the techniques were useful for both disciplines: they allow one to calculate distances on a star map or a on terrestrial map.³⁶ But both the tables and the techniques were explicitly taken from Ptolemy’s *Cosmographia*, and Lefèvre clearly had in mind that his reader would be prepared to read geographical works. He concluded his list of seven techniques with the claim that “quickness in thinking through these intervals and distances will have great value for the *Cosmography* of Ptolemy and the *Geography* of Strabo.”³⁷ The goal was cosmographical literacy.

The overlap of genre between the *Sphaera* and the new handbooks of cosmography has been noted several times before.³⁸ I would emphasise that this overlap

³⁴ (Lefèvre 1495, b iir): “...ex Ptolemaeo deprompta.”

³⁵ Determination of longitude from astronomical principles required time-keeping devices sufficiently reliable over long distances to give a time measurement independent from the sun—a practical impossibility before the eighteenth century.

³⁶ (Lefèvre 1538, 14r): “Ex his quoque et determinatis in praecedente commento, distantias tum in caelo, tum in terra cognoscere promptum est.”

³⁷ (Lefèvre 1538, 14v): “Et horum intervallorum distantiarumque cognoscendarum promptitudo non parvum ad Cosmographiam Ptolemaei et Geographiam Strabonis habet momentum.”

³⁸ (Johnson 1953, 296–99) already offered some suggestive comments; see now (Weiss 2011; Mosley 2009).

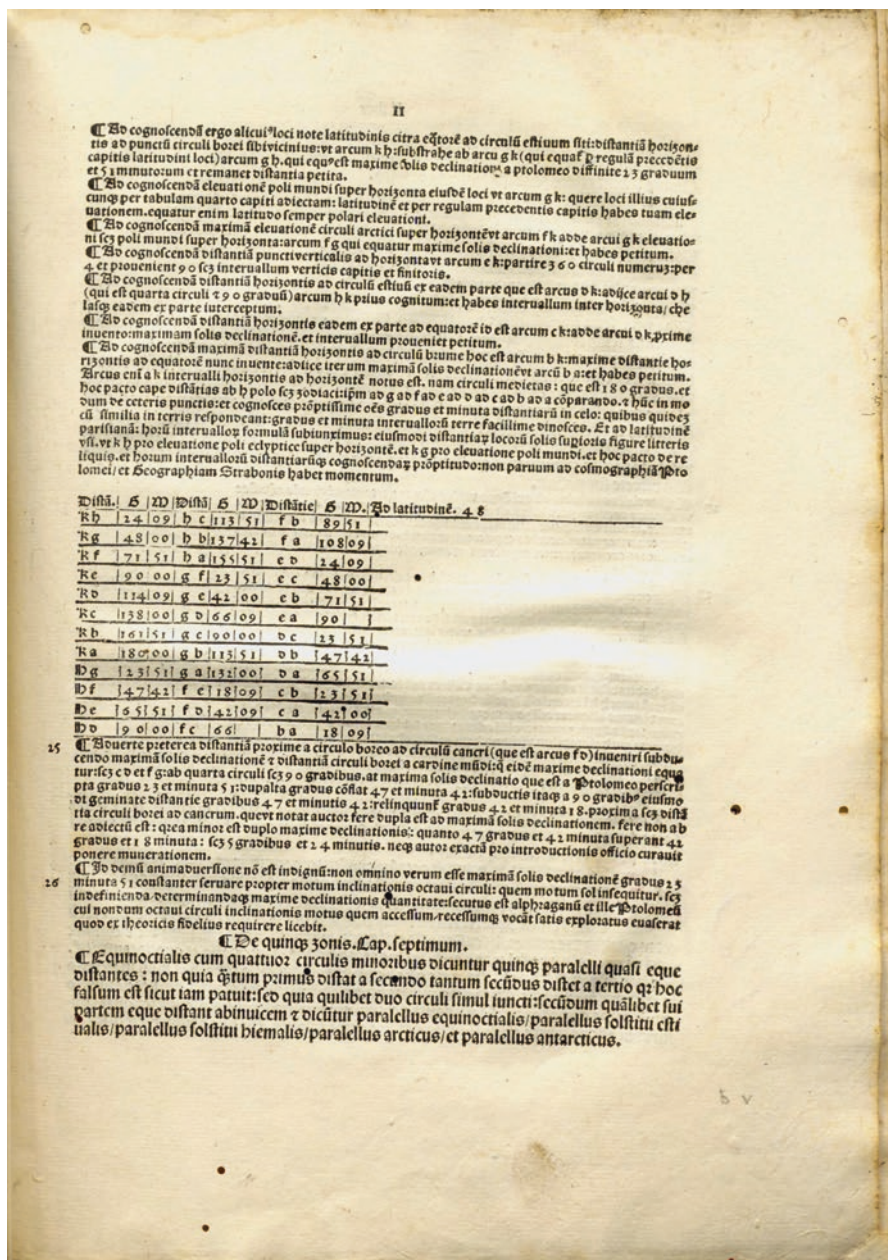


Fig. 2.3 Seven rules, with a specimen table, for calculating various problems of latitude. (From (Lefèvre 1516, b iiiii)). University Library Basel, CC II 7:3, <https://doi.org/10.3931/e-rara-49305/> Public Domain Mark)

begins quite deeply already within the Fabrist commentary on the *Sphaera*, well before the cosmography manuals just mentioned (see Appendix). It would be simplistic to claim a linear influence from Lefèvre's *Textus de sphaera* to those early manuals, but there exist some suggestive links. Prosopographically, three of the earliest writers on the topic were connected to Lefèvre and his circle. The first is Matthias Ringmann, who wrote his *Cosmographiae introductio* (1507) to accompany the gores for a Ptolemaic map by Martin Waldseemüller (ca. 1472–1520).³⁹ Ringmann quite likely had been Lefèvre's student in Paris; by most accounts he had gone to the grammar school at Sélestat. Certainly he was close to the circle of Alsatian students who first studied in Sélestat and then went to Paris to study for the MA with Lefèvre, before returning to participate in the Rhineland community of humanists that would attract Erasmus to Basel: the sons of Johann Amerbach (1440–1513), Johann Sapidus (1490–1561), Michael Hummelberg (1487–1527), and Beatus Rhenanus (1485–1547).⁴⁰ All of these were Lefèvre's students; it is not surprising then that Ringmann identified Lefèvre's own textbooks as a model for his *Grammatica figurata* (1509) (Ringmann 1509, 2r).⁴¹

The second case is Henricus Glarean, whose manuscript handbook from 1513 is also among the earliest examples of the genre. The book seems to have been composed near the end of Glarean's stay at the University of Cologne, probably as part of his teaching at the Bursa Montis just before he moved to teach at Basel in 1514. Although it was not until 1517 that Glarean spent time in Paris with Lefèvre, there are suggestions that he was already familiar with the older humanist's commentary on Sacrobosco. Glarean's own teaching copy of the *Sphaera* from this period is a 1493 edition of Sacrobosco. Glarean had transformed the book into a compendium of annotations from a wide range of other texts, including other versions of the *Sphaera*. Two sets of annotations are enough to make the point. One is a table of the various climates, together with a diagram that is directly copied from Ringmann's *Cosmographiae introductio* (Fig. 2.4 right). The second telling note is the pyramids we have already seen from Lefèvre's 1495 commentary on the *Sphaera*, complete with a cross-section of the heavenly sphere showing the circle of pyramids fanning from earth to zodiac (Fig. 2.4 left). Evidently, already during his teaching at Cologne from 1507 to 1513 Glarean had set Ringmann's cosmography alongside Lefèvre's *Textus de sphaera*, even as he was compiling his own *Geography* (with its own set of maps expanding on Waldseemüller's charts).⁴² In this trend-setting early stage—Glarean's handbook would inform Peter Apian's (ca. 1495–1552) cosmographical handbooks (Chap. 9)—Ptolemaic cartography is impossible to separate from the genre of the *Sphaera*.

³⁹The relation between Waldseemüller and Ringmann is discussed in (Laubenberger 1982; Johnson 2006).

⁴⁰On this circle, see (Bietenholz 1971; Oosterhoff 2014).

⁴¹More generally on the relationship between Ringmann and Lefèvre, see (Schmidt 1879, 90–91, 121–23; Margolin 1972).

⁴²Glarean's associated maps are extant. See the book list of (Fenlon and Groote 2013, nos. 57, 119). A description can be found in (Heawood 1905). More generally, on Glarean's geographical teaching, see (Johnson 2013), who presents Glarean's astronomy as part of his geography; the argument could equally go the other way.

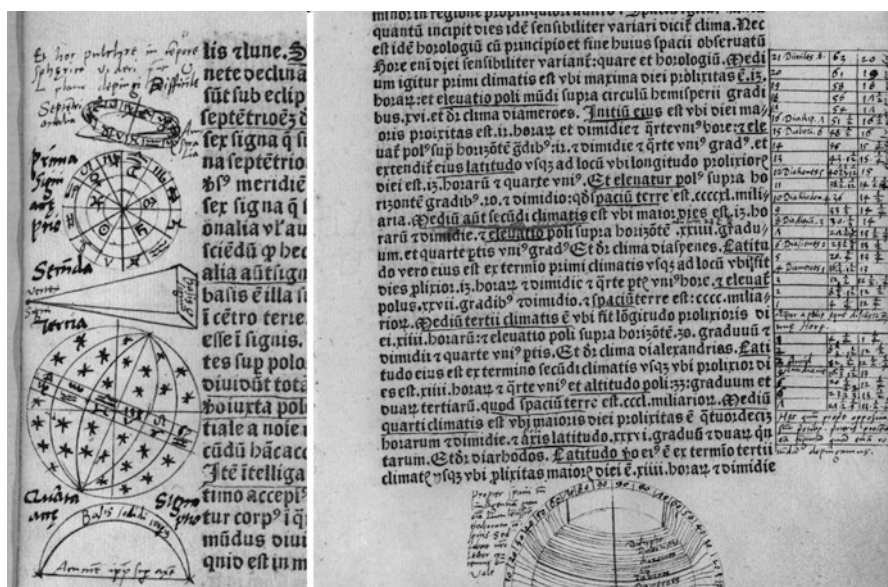


Fig. 2.4 On the left, the diagrams closely follow those given in Lefèvre's *Textus de sphaera* (see also Fig. 2.2 right). On the right, the bottom figure has been hand-copied directly from (Ringmann 1507). From (Sacrobosco 1493, fol. 5v, 12r). University Library Munich, 4 Inc.lat.310 no. 6 <https://nbn-resolving.org/urn:nbn:de:bvb:19-epub-11720-8>

A third example is taken up by Angela Axworthy in much closer detail: Oronce Fine's *De mundi sphaera, sive Cosmographia* (first edition 1532) (Chap. 8). Here I simply wish to highlight the book's debt to Lefèvre. While it is not clear how closely Fine and Lefèvre associated in Paris, their intellectual filiation is not in doubt: Fine's first significant contribution to the mathematical writing and illustration that made him famous was his frontispiece for Simon de Colines' 1521 edition of Lefèvre's *Textus de sphaera*.⁴³ The title of Fine's own *De mundi sphaera, sive Cosmographia* already betrayed its origins in Sacrobosco, and a glance at the contents confirms that its first five books quite closely follow the *Sphaera* (see Appendix). Moreover, the text itself depends considerably on Lefèvre's commentary, even augmenting Lefèvre's use of tables. Book 2 adds star charts, giving not only the locations of cities on the earthly grid, but the longitudes and latitudes of stars on the heavenly grid. Book 3 has at its core the same task as Lefèvre's *Textus de sphaera*, using a selection of small charts to prime the reader for interpreting larger tables of right and oblique ascensions. Building on Lefèvre's work, Fine's *Cosmographia* binds astronomy and cosmography even closer together by underscoring the fact that the astronomer and cosmographer share the same techniques (Besse 2009).

⁴³ On this relationship, see (Axworthy 2016, 28; Pantin 2009a, b).

As Henrique Leitão has argued, Fine's work was open to critique from many angles; but this was precisely because Fine, as the prestigious royal professor of mathematics in Francis I's *Collège Royal*, was the pre-eminent mathematical practitioner of mid-sixteenth-century Europe (Leitão 2009). The cosmographies of Ringmann, Glarean, and especially Fine defined the shape of cosmography in the Renaissance—and they cemented Lefèvre's version of the *Sphaera* into the foundations of cosmography.

5 The Material *Sphaera*

The techniques of actual measurement and calculation discussed above bring us back to lathes and the question of how manipulation and models relate to the physical world. By the seventeenth century, the art of turning stood in for the manual use of mathematics to rival and control nature's untiring motions. Princes from Maximilian I (1459–1519) and Rudolf II (ca. 1401–1495) to Peter the Great sought recreation in the art of turning. Courtly collections of wonders from Dresden to the Palazzo Vecchio of Florence included fine pieces of ornamental turnery (Klaus 1985, 2004; Connors 1990). In 1565 Samuel Quiccheberg (1529–1567) recommended that such collections devote an entire room to such tools and their artefacts.⁴⁴ Turned ivories among surviving examples in the Kunstkammer of the Electors of Saxony, in Dresden, are material ruminations on the five platonic solids, examples of how turning became a metaphor for mechanical control of nature, or what Horst Bredekamp has called the “cult of the machine” (Korey 2007; Dupré and Korey 2009, 417; Bredekamp 1995).⁴⁵ Such lathework quoted in matter the *Timaeus*, where Plato set gave his analogy of the cosmos as spinning bowls formed by a divine Craftsman, setting up his account of the five solids as the building blocks of the universe. Over the course of the sixteenth century, the image of a lathe permeated versions of the *Sphaera*, part of the construction of turning as a material topos.

In 1495, the lathe was not yet a commonplace depiction of the heavenly sphere. When he introduced it in his *Textus de sphaera*, Lefèvre likely had in mind the Platonic image of God as artifex; in his *Astronomicon* (1503) he offered planetary astronomy as a way for human souls to imitate the circular, productive motions of the first Artisan (Lefèvre et al. 1503, xcviir). With the lathe, Lefèvre set readers the problem of reasoning about how mathematical forms regulate matter, and especially the movement of that matter. Although axial motion was a common question in late medieval physics, the metaphor of the lathe was problematic for other reasons.⁴⁶

⁴⁴ (Quiccheberg 2013, 72): “A workshop of turner's equipment and turning and joining tools, such as those considered among most princes and patricians to belong to the domain of the more congenial arts.” More generally, see (Maurice 1985, 2004).

⁴⁵ On the metaphor *machina mundi* in this period, see (Popplow 2007).

⁴⁶ Late medieval reflections on revolving objects include Gaetano da Thiene, commenting on the Merton calculators: see (Wallace 1981, 55–56; Shank 2007b, 2009).

Even Plato had observed that mathematics was only fitted to matter by means of “bastard kind of reasoning” (Plato, *Timaeus*, 52b2).

How much could the metaphor describe what the *Sphaera* called the material sphere? Not all of Lefèvre’s own readers were happy with the lathe. In 1498, Pedro Ciruelo’s (1470–1554) own commentary on the *Sphaera* provides evidence that Lefèvre’s commentary was already being read more widely at the University of Paris (Chap. 3). His ambivalence, however, shows that the lathe example touched on unresolved issues within the philosophy of mathematics. First he paraphrased Lefèvre’s example at length, anonymously as the “account of others.” Then he noted that “although this seems to be a beautiful and ingenious case, nevertheless this was not what Euclid had in mind.”⁴⁷ The primary reason explicitly draws on Aristotle’s misgivings about mathematical abstraction in *On the Soul* and the *Metaphysics*: “since sensible matter cannot take those forms or shapes that mathematicians think up.”⁴⁸ Ciruelo was a talented mathematician, who regularly expressed his appreciation of Lefèvre, Clichtove, and Bovelles, yet he was worried that Lefèvre’s lathe example was overoptimistic about how well mathematics can define a physical object.

Still, the visual echoes of Lefèvre’s lathe suggest that the example was too powerful to let go. Readers of early books often, like Glarean, took images that they found useful from other versions of the *Sphaera* and copied them into the margins of their own copies. One 1508 version from Cologne reveals just this: at the top of the page the reader has drawn in the metal blade, defined as the “curve of the circumference;” a little ways down the page is drawn the lathe, which “is an example of the first definition [i.e. of Euclid’s definition]” (Fig. 2.5). To someone whose mathematical literacy is set by twentieth- or twenty-first-century visual culture, the series of geometrical “principles” that introduced most editions of the *Sphaera*—and also cosmography manuals—may seem somewhat superfluous. But such visual cues required cultivation in the sixteenth century.

An important turning point in this visual topos comes in the 1530s, in the stripped-down versions of the *Sphaera* published at Wittemberg, often with Philip Melanchthon’s oration on astronomy. The first chapter addresses the *definitio sphaerae*, and for the first several editions, the only commentary added to Sacrobosco’s words is the diagram of a lathe, before moving on to the next chapter on the division of the sphere (Fig. 2.6 left). After 1538, a further brief scholium was added, citing the Greek edition of Euclid. This note did not eclipse the old lathe, however, but complemented it with a new image of a pseudo-lathe (Fig. 2.6 right). Where the first lathe shows how to create a solid sphere from a semi-circular hollow, the second image does something slightly less intuitive. It takes a semicircular surface, and asks the viewer to imagine it spun around an axis—the space it sweeps out exemplifies a *hollow* sphere. The place of this example between physical object and

⁴⁷ (Ciruelo 1498, b ir): “Sed quamvis hec pulchra et ingeniosa videantur, hanc tamen non fuisse Euclydis mentem.”

⁴⁸ (Ciruelo 1498, b ir): “Cum materia sensibilis non tales formas seu figuras recipere possit quales mathematici concipiunt ut satis probatur in primo de anima et in tertio methaphysice.”

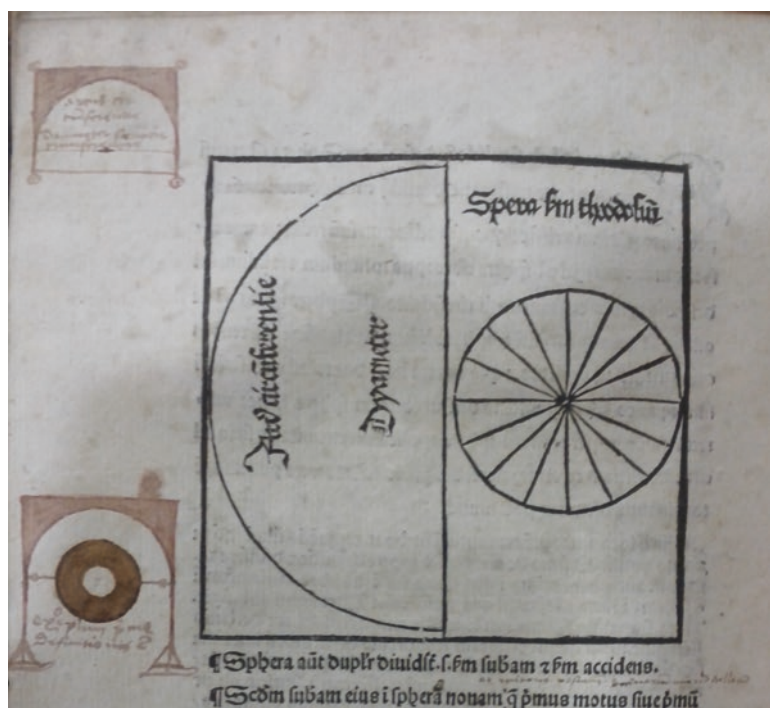


Fig. 2.5 A reader adds diagrams of the material lathe, inscribing above “arcus circumferentie,” and below, “exemplum prime definitionis est.” (From (de Budweys 1508, A iiii v). Newberry Library, Ayer oQB 41.S12, (image by Author/Public Domain))

imagined concept is underscored by two tiny figures standing on the ground below the sphere, allowing the reader to imagine themselves standing below an enormous space. By the second half of the sixteenth century, this second, inverted lathe was widely common in the genre of the *Sphaera*, including versions by Giuntino Giunta 1477–1521, Elie Vinet (1509–1587), and Franco Burgersdijk (1590–1635).⁴⁹

To what extent was this object on a lathe identified with the physical cosmos? Typically, the figure introduced a discussion of the “material sphere.” One might suppose this meant the actual nested orbs that were the subject of Sacrobosco’s planetary astronomy (Barker 2011). This seems to have been the case for Lefèvre, who took no trouble to distinguish the “machina mundi materialis” from the actual cosmos. But over the course of the sixteenth century, the material metaphor seems to have become more troubling. One example is the *Epitome astronomiae* of Michael Maestlin (1550–1631), which gives the inverse, Wittenberg version of the lathe to exemplify the Euclidean definition of the sphere (Maestlin 1597, 10). Maestlin qualified the “material sphere” differently than Lefèvre had done: “We give the name ‘material sphere’ to the instrument that represents the outermost, convex sur-

⁴⁹ See also the versions of the *Sphaera* by Vinet and Burgersdijk (Chap. 11).



Fig. 2.6 Lefèvre’s lathe example became mainstream in the enormously popular Wittenberg edition of 1531 (left), which was then augmented in 1538 with an additional outsized example of a revolving semi-circle (right). Left: From (de Sacrobosco 1531, B i v). Bavarian State Library, H.g.hum. 18 I, <http://mdz-nbn-resolving.de/urn:nbn:de:bvb:12-bsb00039827-2>. Right: From (de Sacrobosco 1538, B ii r). Bavarian State Library, Astr.u. 154, <http://mdz-nbn-resolving.de/urn:nbn:de:bvb:12-bsb00020992-1>, <http://hdl.handle.net/21.11103/sphaera.101106>

face, or the circles that define it, of the highest heaven (which we call the ‘natural sphere’).⁵⁰ In other words, Maestlin applied the term “material sphere” to the instrument or model (perhaps thinking of an armillary sphere) rather than to the heavens themselves.

The lathe had become a commonplace, within the genre of the *Sphaera* as well as at courts. Moreover, the function of that commonplace seems to have shifted ever so slightly. Only a much larger study could adequately consider the range of concerns implicit in such a commonplace.⁵¹ But this brief sketch suggests that the lathe

⁵⁰ (Maestlin 1597, 13): “Ut sphaeram Materialem appellamus illud instrumentum, quod ultimi coeli extremam seu convexam superficiem (quam vocamus, Sphaeram Naturalem) vel Circulos in ea. conceptos, repraesentat.”

⁵¹ A study considering the range of concerns implicit in the lathe as a commonplace would include reflection on movement within mathematical argument, e.g. (Axworthy 2017, 2018). On the epistemic status of armillary spheres and globes, see (Mosley 2006a, b).

pushed to the foreground the question of what constitutes an adequate model. To what extent, that is, can a tool serve as a metaphor for the universe; to what extent do the qualities of one object or domain transfer over to another? Maestlin (and others who implicitly agreed by reusing the image) seems to have shifted away from accounts that seamlessly elided the lathe model with the materiality of the heavenly referent, opening a space for alternative theories of the heavenly sphere's composition. At the same time, he paid closer attention to the visual work of such machines *as* machines, suggesting that the model helped to think about physics.⁵² Perhaps this is reading too closely—but, if not, then the paradigmatically Ptolemaic *Sphaera* helped to stage some of problems that a new mathematization of motion would set. At all events, for Maestlin as well as for Ciruelo, the example of the lathe prompted reflection on the relationship of model to original, of mathematics to matter.

6 Conclusion

Taken together with the tables and cosmographical tools discussed earlier in this chapter, the example of the lathe suggests the multiple trajectories that could meet within a capacious and growing genre such as the *Sphaera*. First, the *Textus de sphaera*, first printed in 1495, presented techniques for calculation that became more widespread in books on the *Sphaera* during the course of the sixteenth century. Lefèvre offered commentary on literary and terminological questions, offering the kind of qualitative mastery of the science of the stars that any university educated man was expected to have in the Renaissance. As I show elsewhere, this skill set can be traced through later versions of the *Sphaera*, and constitutes an important shift in the wider cultural expectation of early modern Europe that educated people should be literate in the arts of number as well as the alphabet (Oosterhoff 2020).

Second, I have argued that Lefèvre's *Textus de sphaera*, first published in 1495, brought together the techniques of Ptolemy's *Geography* with the genre of the *Sphaera*. Therefore, Lefèvre's book could be read as a cosmographical handbook; and I have suggested that it did set a precedent for Ringmann, Glarean, and Fine. Lefèvre's expectation that readers of the *Sphaera* should be interested and able to calculate for themselves locations on a map fed the new genre of cosmography.

A third trajectory is particularly clear with the lathe, a visual topos that originates in Lefèvre's commentary. The reformulation of this topos offers a chance to consider the accruing visual culture of the *Sphaera* in print, and the way that a visual topos that could travel independently of verbal commentary. While Lefèvre's verbal account was eventually made redundant by new versions of the *Sphaera* that incorporated new tables and rules for their use, the visual power of the lathe seems to have helped it outlast Lefèvre's own text. As a material metaphor it reprised the

⁵² E.g. (Lefèvre 2004). These twin shifts would produce a paradox: mathematics is separated from the heavens, while at the same time the machine's motion is conceived of *more* mathematically. For one discussion of the tensions at play, see (Gal and Chen-Morris 2013, 117–160).

Timaeon account of the universe as a crafted mathematical object; as a visual object, particularly in the Wittenberg tradition where it came to represent a *hollow* or absence, it kept the viewer in mind of the difference between model and reality—a crucial cognitive habit in the later sixteenth century as alternative world models became public.

Appendix. Contents of the Early Handbooks of Cosmography

Sacrobosco, <i>Sphaera</i>	Matthias Ringmann, <i>Cosmographiae</i> (1507).	Heinrich Glarean, <i>De geographia liber unus</i> (Basel: Jo. Faber. Emmeus, 1527) [MS c. 1513]	Peter Apian, <i>Cosmographia</i> (1529).	Oronce Fine, <i>Cosmographia</i> (1st ed. 1532)
Lib. I				Lib. I
– Definition of the sphere – Four elements – Revolutions of the heavens – Rotundity of the earth – Diameter of the earth	1. Basics of geometry 2. Sphere, axis, poles	1. Principles of geometry and spherical astronomy 2. Celestial and planetary spheres 3. Motions of the spheres	1. Definition of cosmographia 2. Motion of the sphere	– The world, its parts and motions
– Lib. II				Lib. II
– Celestial circles – North, south poles – Division of the zodiac – Ecliptic – Colures, meridian, horizon, – Tropics – Five zones [parallels]	3. Celestial circles 4. Various degrees of the sphere 5. The five heavenly zones 6. Parallels	4. Axis, poles 5. Right, oblique spheres 6. Greater and smaller circles (ecliptic, colures, meridian, etc.) 7. Composition of the material sphere 8. Elevation of the poles 9. The five zones 10. Parallels	3. Definition of a sphere, its circles, signs of zodiac 4. The five zones 5. The parallels	– Equator, poles, zodiac – Longitude and latitude – Meridian – Minor circles – Five zones

(continued)

Sacrobosco, <i>Sphaera</i>	Matthias Ringmann, <i>Cosmographiae</i> (1507).	Heinrich Glarean, <i>De geographia liber</i> <i>unus</i> (Basel: Jo. Faber. Emmeus, 1527) [MS c. 1513]	Peter Apian, <i>Cosmographia</i> (1529).	Oronce Fine, <i>Cosmographia</i> (1st ed. 1532)
Lib. III				Lib. III
– Rising and setting of signs – Chronic, solar risings – Right ascensions – Inequality of days – Oblique ascensions – Living at equator – Arctic circle – Seven climes	7. The climes	11. The climes 12. Technique for measuring the earth 13. Breadth of the earth 14. Longitudes of cities 15. Units of measurement	6. The climes 7. Longitude 8. Latitude 9. Calculating solar altitude 10. Longitudes of places 11. Units of measurement ...	– Rising and setting of stars – Right and oblique ascensions
Lib. IV				Lib. IV
– Movement of the sun – Equant, deferent, epicycle – Lunar eclipse	8. Winds 9. Division of the earth, the ends of the sea, and distances of various islands [10.] A quadrant useful to the cosmographer	16. Winds 17. Ptolemy's method for depicting the world 18. The image of the world 19. Putting paper on a globe (i.e. gores) 20. Geographical names 21. Division of the earth 22–40. Europe... Africa...Asia...and regions beyond Ptolemy		– Inequality of days – Calculating equal/inequal times – Calculating solar altitude Lib. V – Parallels – Longitude and latitude – Calculating distances – Winds – Sines and chords ...

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